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Object-defined Resolution Below 0.5Å in Transmission Electron Microscopy – Recent Advances on the TEAM 0.5 Instrument

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Over the last decades, electron microscopy has developed rapidly. The Transmission Electron Aberration-corrected Microscope (TEAM) project, which was initiated as a collaborative effort to redesign the electron microscope around aberration corrected optics is at the forefront of this development [1]. The instrument is designed to achieve 50 pm resolution. However, the ability to resolve deep sub–Ångstrom spacing entails a number of questions that can now be addressed. Among them is an ongoing debate about the physical meaning of resolution. Traditionally established strategies employed to address resolution include the recording of Young fringes, the detection of image Fourier components in STEM images, the demonstration of a suitable peak separation in periodic lattices or signal width measurements from images of single atoms, to name a few. The drawback of these different approaches is that seemingly conflicting results are produced [e.g. 2]. Further, they define resolution through a selectable object, in opposition to light microscopy where resolution is instrument-defined. In this situation, the TEAM Project adopted the pragmatic view to achieve information transfer below 50 pm by detecting Young fringes in TEM and (660) image Fourier components from gold (111) STEM images at 48 pm. Recently the TEAM 0.5 prototype microscope achieved this goal [3].

In Figure 1 two possible limits to resolution are depicted. In one extreme the electron channeling dominates [4,5] and in the other extreme it is elastic scattering at single atoms [6]. These differences become important if deep sub-Ångstrom resolution is pursued since the channeling model predicts for example that a resolution well below 80 pm cannot be obtained if columns of light elements are imaged. On the other hand, resolution tests using heavy elements with Z~ 80 are less critical since both models converge and allow for 50 pm resolution. Therefore, we used gold (Z=79) crystals to probe for information transfer of TEAM 0.5 and started investigating object-defined resolution to better understand the details of electron channeling.

Figure 2 shows two amplitude images of channeling waves that were reconstructed from 30 experimentally recorded lattice images from gold crystals imaged in [110] and [111] direction with the TEAM 0.5 microscope. Gold atoms are spaced by 0.29 nm in the [110] direction but by 7 nm in the [111] direction. This alters electron channeling significantly. It is seen from the line profiles in Figure 2 that the full width at half maximum of the signals is 67 ± 4 pm and 46 ± 3 pm for Au [110] and Au [111], respectively. The results agree with predictions from multislice calculations that also predict similar effects for HAADF STEM images from Au [110] and Au[111]. Therefore, we conclude that the TEAM 0.5 microscope can resolve column spacings below 0.5 Å close to the Rayleigh resolution limit if the objects are carefully chosen and prepared. However, in general electron channeling can limit the object-defined resolution to values above 50 pm in both STEM and TEM images [7].

[1] The TEAM project is supported by the Department of Energy, Office of Science , Office of Basic Energy Sciences.

[2] P.E. Batson, Ultramicroscopy 96, 239 (2003)
[3] [1] http://ncem.lbl.gov/TEAM-project/index.html
[4] A.J. den Dekker, S.Van Aert, D. Van Dyck, A. Van der Bos, P. Geuens, Ultramicroscopy 89, 275 (2001)
[5] S. Van Aert, A.J. den Dekker, D. Van Dyck, A. van den Bos, Ultramicroscopy 90, 273 (2002)
[6] L. Reimer, Transmission Electron Microscopy, Springer, Optical Sciences, Berlin 1993, p. 152
[7] NCEM is supported by the Department of Energy under Contract # DE-AC02-05CH11231.

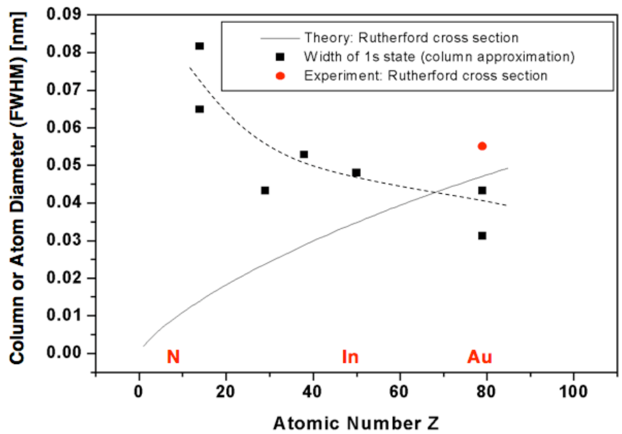

Figure 1: Predicted dependence of the atom column diameter in the channeling approximation [2,4] and of the total elastic cross section for scattering at single atoms [5] on the atomic number Z for most elements from the Periodic Table.

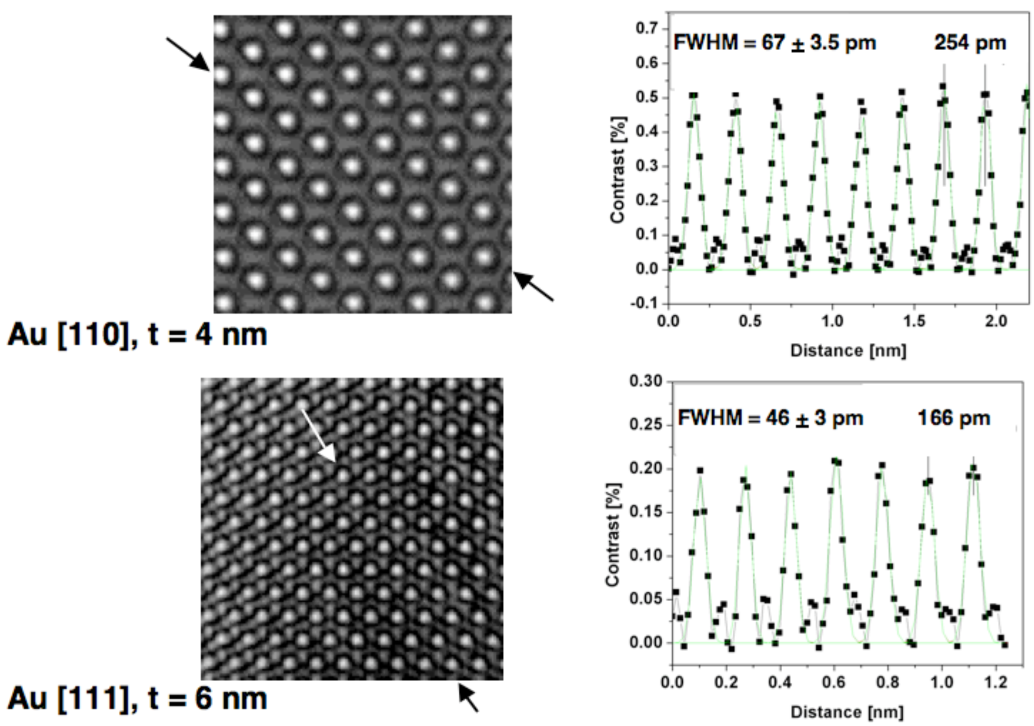

Figure 2: Amplitude images of channeling waves that were reconstructed from lattice images of gold [110] and gold [111] crystals recorded with the TEAM0.5 microscope. The crystal thickness t is indicated. The extracted signal width from the associated line profiles proves that an object-defined resolution below 50 pm is obtained in Au [111] that increases to 67 pm in case of Au [110].